SWAMPLANDS FOR SEWAGE EFFLUENTS

USE OF SWAMPLAND AS A NATURAL SINK FOR RECEIPT OF SEWAGE EFFLUENT

by

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1. Summary

Sewage effluent from Hay River, N.W.T. is released into a small stream which meanders through natural swampland before flowing into Great Slave Lake. A study has been made of the effect of the effluent upon the swampland. Some observations have also been made upon the swampland at Pine Point into which the Pine Point effluent drains. The swamplands at the two places are closely similar and the report deals almost exclusively with the much more extensive data obtained at Hay River.

The effluent creek at Hay River flows for some 6,200 metres through relatively flat terrain and intermittently broadens into pools bordered with and connected by dense stands of emergent plants, principally *Carex* species. A series of sample sites were selected upon this stream and upon a similar but undisturbed creek in the vicinity. Chemical and biological samples have been taken at these sites since August 1972, and some observations were made during a preliminary visit in May 1972. In addition, some data is available in the reports on the Hay River sewage lagoons by Grainge and Shaw (1970) and Grainge and Frith (1971).

The upper 2,500 metres of the effluent creek show evidence of damage by the sewage effluent; the biological diversity is reduced, oxygen levels are low, and various other chemical parameters, including BOD and total soluble phosphate, are high. Counts of total coliform bacteria are also high.

At site E5, some 4,000 metres downstream, the condition of the effluent creek is comparable to that of the control creek both chemically and biologically. BOD, phosphate, and total coliform counts are low, and the concentration of dissolved oxygen is high or very high. The condition of

both the effluent and the control creeks at their mouths is less good than further upstream; this is probably due to the effects of stagnation during the summer when flow into Great Slave Lake ceases completely.

From the data for BOD, phosphates and total coliform bacteria it is evident that the effluent creek and its watershed effect substantial secondary and tertiary treatment upon the effluent sewage load. BOD and phosphates are both reduced by more than 98% between the site of inflow and site E5.

From measurements of the area of the watershed and estimates of the average contributing population during the four years since the lagoons were brought into operation, it is concluded that the sewage resulting from one man for one year exerts a detectable adverse effect on not more than about 40 square metres of swampland; if the swamp is now in equilibrium with the present sewage load the affected area may be as little as 15 square metres per contributing person.

The sewage effluent is derived from two sources. About 177,000 gallons per day flow into the creek from the two sewage lagoons (which are operated in parallel), and some 30,000 gallons per day are dumped directly into the creek by dump trucks which haul sewage from parts of Hay River not connected to the sanitary sewer system.

On the basis of the study a series of recommendations is made; these mainly concern the release of primary-treated sewage effluent into natural swampland in northern Canada.

2. Introduction

2.1 Nature and Scope of Study

This is an examination of the effects of the effluent from the primary sewage lagoons at Hay River, N.W.T., upon natural swampland in the vicinity.

2.2 Objectives

2.2.1 To ascertain the effect of effluent from the short retention lagoons at Hay River upon the swampland community by examination of the standing crop, community structure and diversity, primary production, water chemistry and groundwater movement in the receiving swampland and in control sites.

2.2.2 To derive, from the evaluation conducted in 2.2.1, recommendations regarding the quality and quantity of sewage effluents which might safely be received by natural swampland in northern Canada.

2.3 Relation to Pipeline Development

During the construction of the Mackenzie Highway and the possible construction of pipelines down the Mackenzie Valley many temporary camps will be required for construction personnel, each with a problem of domestic sewage disposal. Due to the temporary nature of these sites an effective but inexpensive method of disposal is sought. It has been suggested that both primary and secondary sewage treatment may be effected by natural swampland but quantitative data have not hitherto been available.

Since there is abundant swampland available along almost the entire route of the Mackenzie Valley, this method would, if proven effective, greatly simplify the problem of sewage disposal. The method may also be of value to small permanent settlements in northern Canada.

3. Current State of Knowledge

Practically nothing is known of the effect of sewage effluent upon swampland. A previous study of the creek into which Hay River sewage effluent flows (Grainge and Shaw, 1970) has shown that in comparison with the raw sewage, the water at the mouth of the creek shows greater reduction in various chemical parameters than could be expected from dilution (see Table I). From this it is evident that nutrient removal occurs during passage of the effluent through the swampland.

It has been suggested (Grainge, Greenwood and Shaw, 1972), in reference to the discharge of sewage effluent to tundra and swampland, that "it is hard to find great fault with this practice, no matter how little treatment is achieved in the primary settling ponds". However, failure to observe deleterious effects may result either from an absence of effects or an absence of observations. The present study is designed to remedy the lack of observations.

TABLE 1

Selected chemical parameters (all in mg/1) in raw sewage and at the mouth of the effluent creek, Hay River.

(Data from Grainge 1970)

Parameter	Raw Sewage (Mean)	Effluent creek	% reduction
BOD_5	75	2.2	97
NH_3-N	10.9	0.068	99
PO_4-P (total soluble	5.9	0.2	97
M.B.A.s	2.27	0.04	98
SS	135	16	88
COD	217	68	69
N (Organic)	6.1	1.3	79

4. Study Areas

4.1 Geographic Location

The primary study area is a swampland area located north and west of the town of Hay River, N.W.T. Refer to map, Department of Mines and Technical Survey, Surveys and Mapping Branch. Hay River (85 3/13) between Military grid references 648418 and 632463 or at approximately 60°50'N and 115°50'W.

The creek into which the town of Hay River's effluent is released flows approximately 3.7 miles in a NNW direction from the site of release of the effluent to its site of entry into Great Slave Lake at a point near 1.3 miles west of the mouth of the most westerly channel of the Hay River.

The creek chosen as a control is similar in direction but enters the lake at a point 0.5 miles west of the effluent creek. Both streams flow through a series of channels, ponds and swamps to eventually enter the lake (Map I).

The Pine Point study area is located at a point about 60°50'N and 114°20'W (Map II). The sewage from the town of Pine Point undergoes primary treatment only and at the point of release flows east into swampland which had no defined creek channel prior to the construction of the lagoon. Since the area has very low relief, flow spreads over an extensive area. This area resembles that between sites E3B and E4A in the Hay River study area (see Map I). It is surmised, on the basis of preliminary winter study, that the flow eventually passes under

the Fort Resolution Highway and thence eventually into Hanbury Creek and the Little Buffalo River.

4.2 Geology and Groundwater in the Hay River Study Area

At the request of the Environmental Protection Service, Department of the Environment, Dr. R.L. Harlan of the Department's Water Resources Branch conducted a reconnaissance hydro-geological survey of the study area. From this study, it seems probable that shallow groundwater flow occurs from the old beach ridges toward the stream channels. Because of low stream gradients, only limited down-channel movement of ground water would be expected.

It is suggested that the apparent lack of surface connections between several of the ponds along the effluent creek is due not to land bridges but to coalescence of a semi-floating organic mat which has advanced from both sides of the pond. The hydraulic connection between successive ponds would thus not be by means of groundwater *per se*, but through the organic mat.

4.3 Pattern of Vegetation Within the Hay River Study Area

The forest through which the effluent and control creeks flow consists mainly of black spruce (*Picea mariana* (Mill.) BSP) with interspersion of jack pine (*Pinus banksiana* Lamb.) on the raised strand lines. The watershed of each creek is delimited by topographical changes of two metres or less and are clearly distinguished by the characteristic vegetation; the marginal areas are dominated by *Populus*, *Alnus* and *Salix* species, and the channels by *Typha* or *Carex* species.

4.4 Hay River Swampland as Representative of Swampland Down the Mackenzie Valley

Although a survey has not been conducted of swampland along the Mackenzie Valley, all the available information suggests that there is substantial uniformity of swampland throughout the area, with *Carex* and *Typha* the predominant genera of emergent vegetation.

5. Method and Sources of Data

5.1 Field Techniques

5.1.1 Water Chemistry

Water samples are taken monthly from ten sample points, eight on the effluent creek and two on the control creek (see Map I). All samples are taken from approximately 6" below the water surface and as close to mid-channel as possible.

Measurements of temperature, pH, specific conductance and dissolved oxygen are made at the time and place of collection using calibrated portable instruments (see Appendix I).

Measurements of water hardness, acidity, alkalinity and dissolved carbon dioxide are made at the time and place of collection when the air temperature is sufficiently high to permit this. At other times these tests are conducted immediately upon return to the laboratory. All other chemical analyses are made in the laboratory.

5.1.2 Bacterial Sampling

Water samples for bacterial counts are taken bi-weekly and are sent immediately by air express to Edmonton where total coliform, fecal coliform, and standard plate counts are performed by the Alberta Public Health Laboratory. The sampling locations and methods are the the same as those employed in section 5.1.1 except that precautions are taken to prevent contamination.

5.1.3 BOD, COD, and Total Dissolved Carbon Sampling

Bi-weekly samples of 32 oz. each are collected as in section 5.1.1 and are shipped to Edmonton by air express as in section 5.1.2. These samples are analysed by the Environmental Protection Service of the Department of Environment, Edmonton, for BOD, COD, and Total Dissolved Carbon.

5.1.4 Plankton Sampling

Qualitative net plankton collections are made monthly at all ten stations with a 6" diameter No. 12 mesh plankton net using a vertical or horizontal haul. The vertical haul is used when sampling is done through the ice. The samples are immediately preserved in 4% formalin solution for subsequent identification.

5.1.5 Hand Collecting

Collections of nekton for qualitative analyses are made monthly at all ten sample stations with a hand net passed through the open water and the submergent vegetation. These organisms are preserved in 4% formalin for later examination. Large nektonic organisms capable of evading this method of sampling were not collected but their presence was recorded if observed by the investigator.

5.1.6 Bottom Samples

Qualitative samples of the bottom material are collected monthly at all ten stations. These collections are made with an Ekman grab where the substrate is suitable, and with a hand net where the bottom is littered with

sticks and logs which interfere with the grab jaws. The collected material is sifted for organisms at site or is preserved in 2 to 4% formalin for future sorting.

5.1.7 Emergent Vegetation Samples

Samples of emergent vegetation are collected for identification from each of the ponds and an estimate of their relative abundance recorded.

Quantitative samples of the most abundant annual plant species are collected at the time of maximum growth from selected plots near every sample station. Samples are taken by removal of all vegetation above water level in quadrats of standard area.

5.1.8 Submerged Vegetation Samples

These are collected and preserved in a similar manner to those in 5.1.7 except that quantitative samples are taken with a sharp-edged tube to remove a core of vegetation.

5.1.9 Phytoplankton Production

Phytoplankton production is estimated using an oxygen light and dark bottle method. Estimates are made at every site at different depths, times of day and times of year in order to provide an estimate of annual production.

5.1.10 Flow Estimates

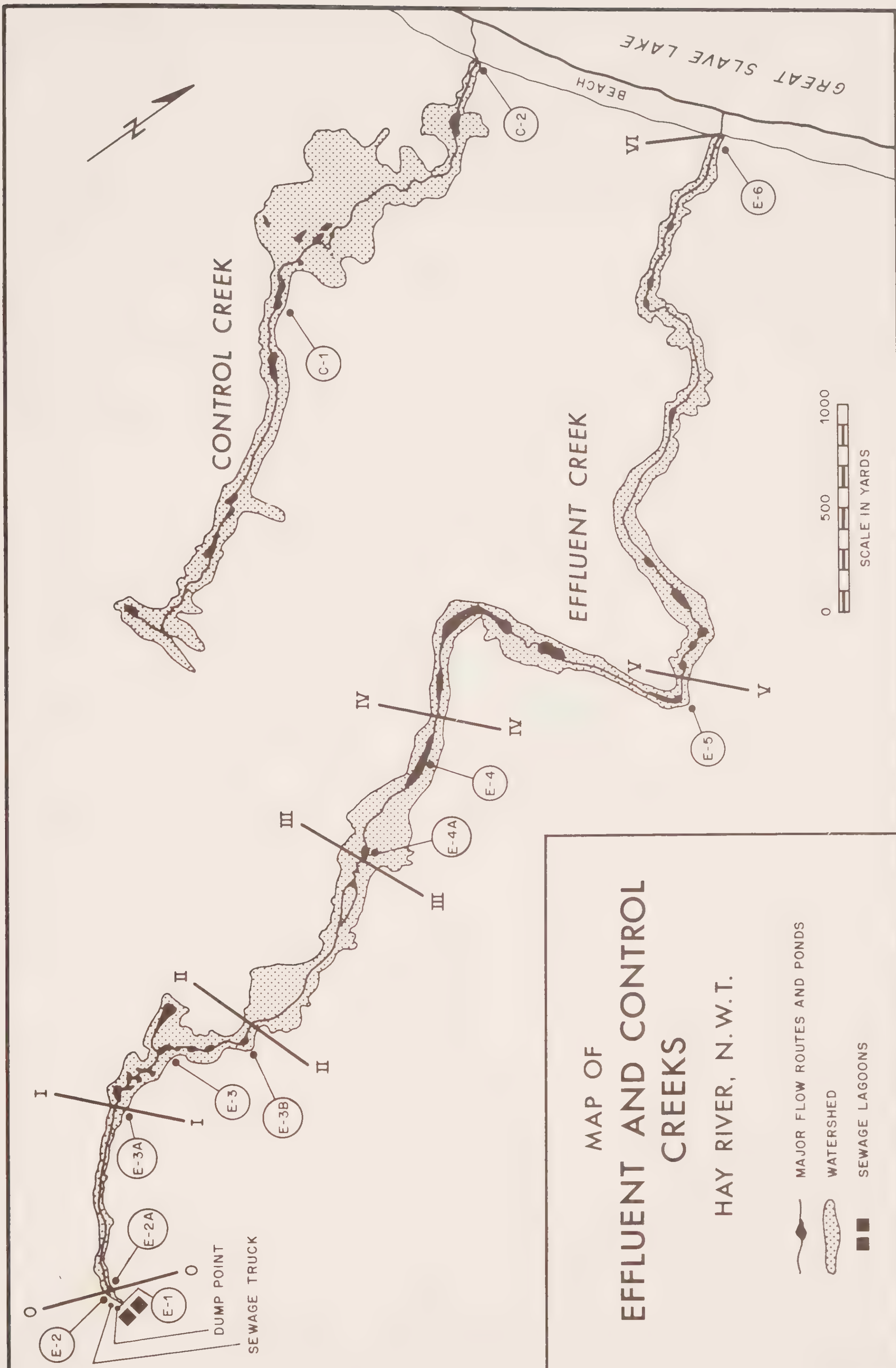
The flow volume from the sewage lagoons and the upstream creek is estimated by using a weir which was constructed in co-operation with the Hay River Office of the Water Survey Branch of Environment Canada.

The sewage trucks release below the weir and their contribution to the flow rate was calculated from a survey of each operator regarding number of loads normally released each week.

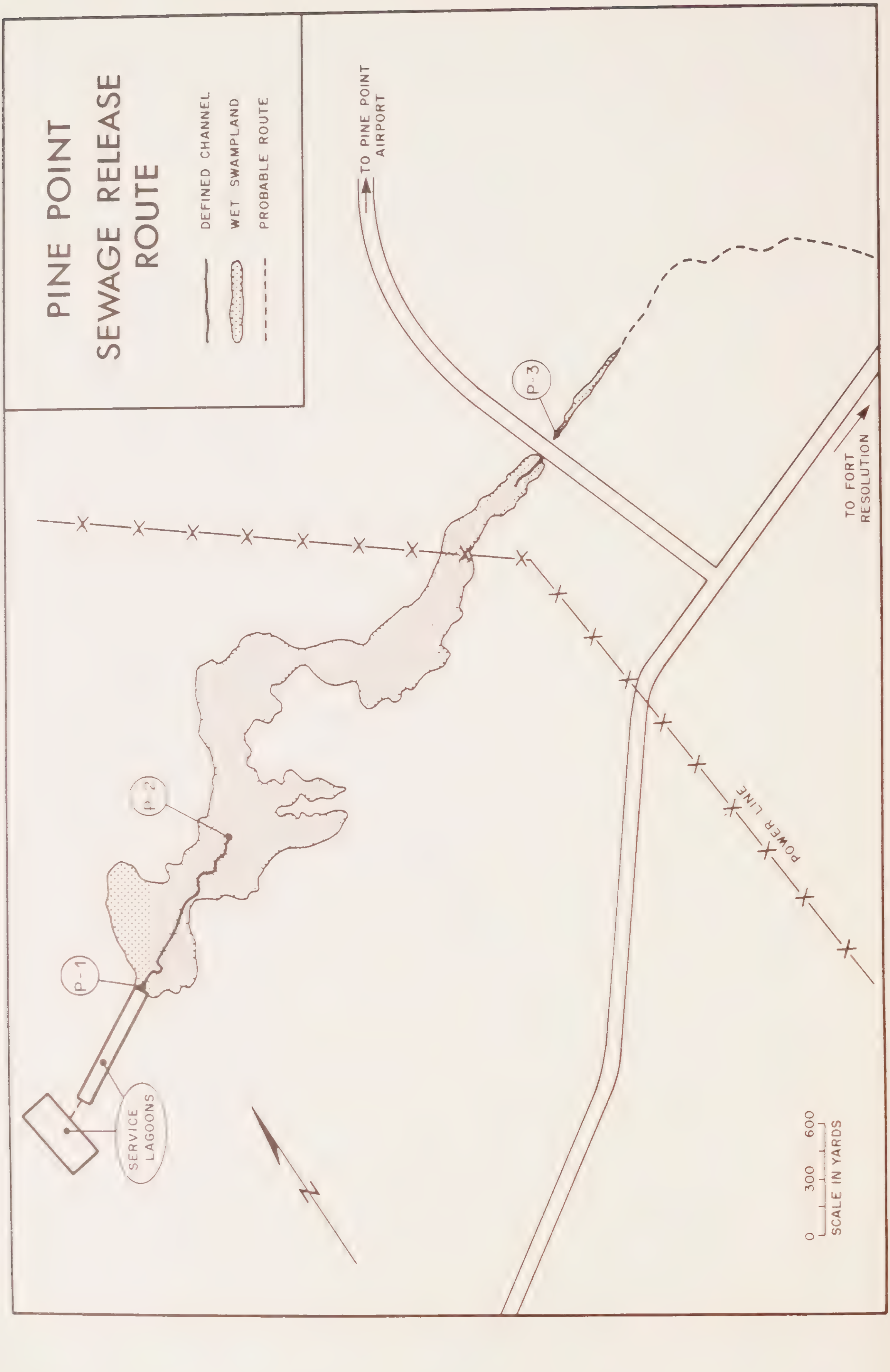
5.1.11 Air Photo Survey

Air reconnaissance of the study area was carried out and the photos taken will assist in vegetation production estimates and stream route evaluation.

Map I


MAP OF
EFFLUENT AND CONTROL CREEKS
HAY RIVER, N.W.T.
MAJOR FLOW ROUTES AND PONDS
WATERSHED
SEWAGE LAGOONS
CONTROL CREEK
EFFLUENT CREEK
GREAT SLAVE LAKE
BEACH
SCALE IN YARDS
0
500
1000
C-1
C-2
E-1
E-2
E-2A
E-3
E-3A
E-3B
E-4
E-4A
E-5
E-6
DUMP POINT
SEWAGE TRUCK
O
I
II
III
IV
V
VI

Map 11


PINE POINT
SEWAGE RELEASE
ROUTE
DEFINED CHANNEL
WET SWAMPLAND
PROBABLE ROUTE
TO PINE POINT AIRPORT
P-3
P-2
P-1
SERVICE LAGOONS
POWER LINE
TO FORT RESOLUTION
N
0 300 600
SCALE IN YARDS

6. Results

6.1 Watershed of the Effluent Creek

6.1.1 Area

From the map (Map I) the total area of the watershed of the effluent creek is found to be approximately 47 hectares, and the creek approximately 6,200 metres in length. Table II shows the areas of selected portions of the watershed.

6.1.2 Flow Results

In early November 1972 the average flow in the effluent creek at the outflow from the sewage lagoons was 177,000 gallons/day. In addition, the sewage trucks which pump out holding tanks of residences and businesses on Vale Island contribute approximately 30,000 gallons/day directly to the creek below the weir. The total flow was approximately 207,000 gallons/day.

6.2 Physical Parameters in the Effluent and Control Creeks

6.2.1 Water temperature

As is shown by Fig. I the surface temperatures of the creeks are closely similar and fall to near 0 C by early November.

6.2.2 Turbidity

Fig. II shows that turbidity is comparable in the two creeks and is generally lowest mid-way down the effluent creek. The high downstream values in both creeks may be attributed to the natural accumulation of organic debris rather than to sewage materials. The very high

TABLE II

AREAS OF PORTIONS OF THE EFFLUENT CREEK WATERSHED

Portion	Area (hectares)	Percentage of total
0-I	1.75	3.74
I-II	6.01	12.83
II-III	8.14	17.38
III-IV	7.39	15.78
IV-V	8.52	18.18
V-VI	15.03	32.09
0-I	1.75	3.74
0-II	7.76	16.57
0-III	15.91	33.95
0-IV	23.30	49.73
0-V	31.82	67.91
0-VI	46.85	100.00

Figure I

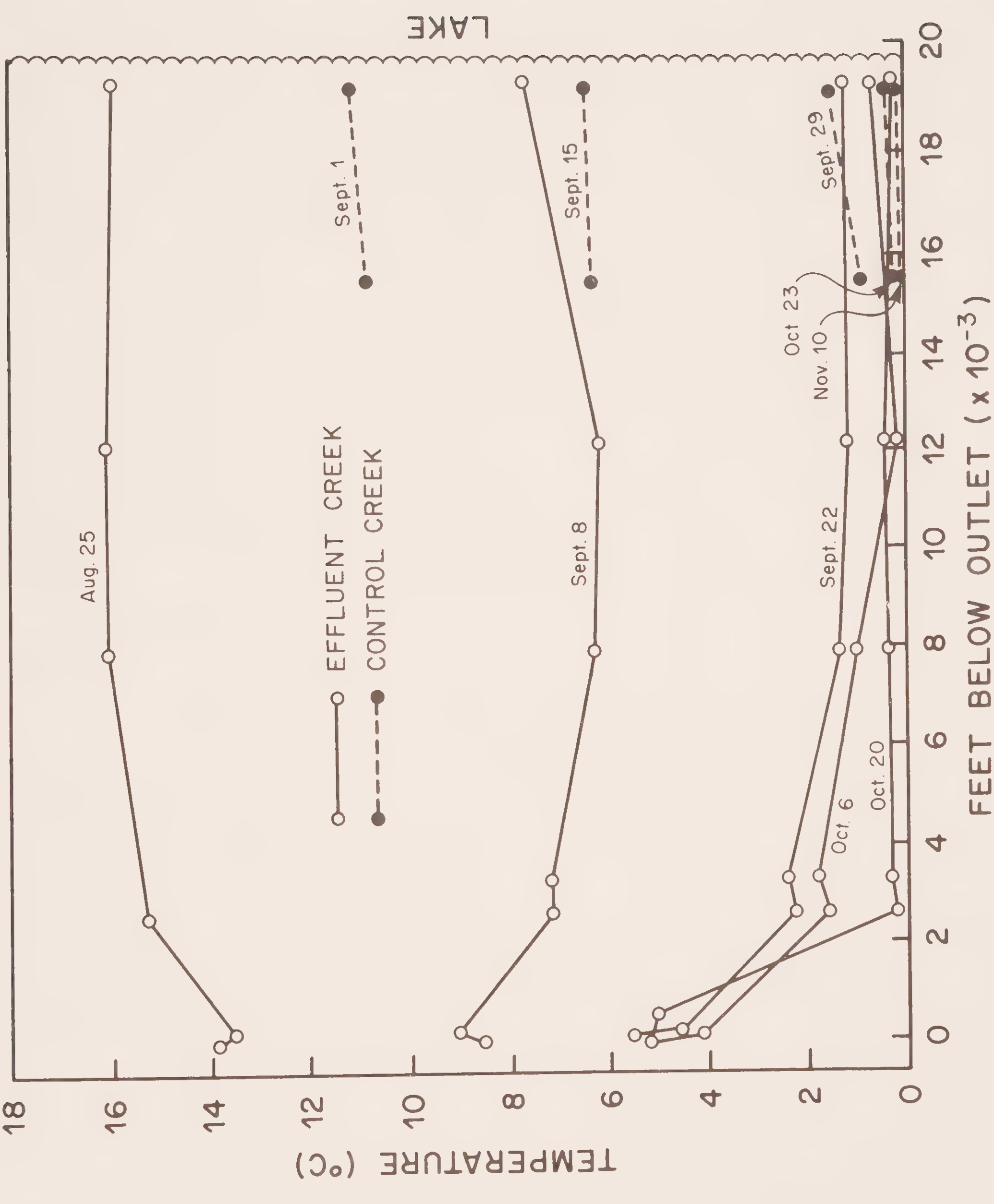
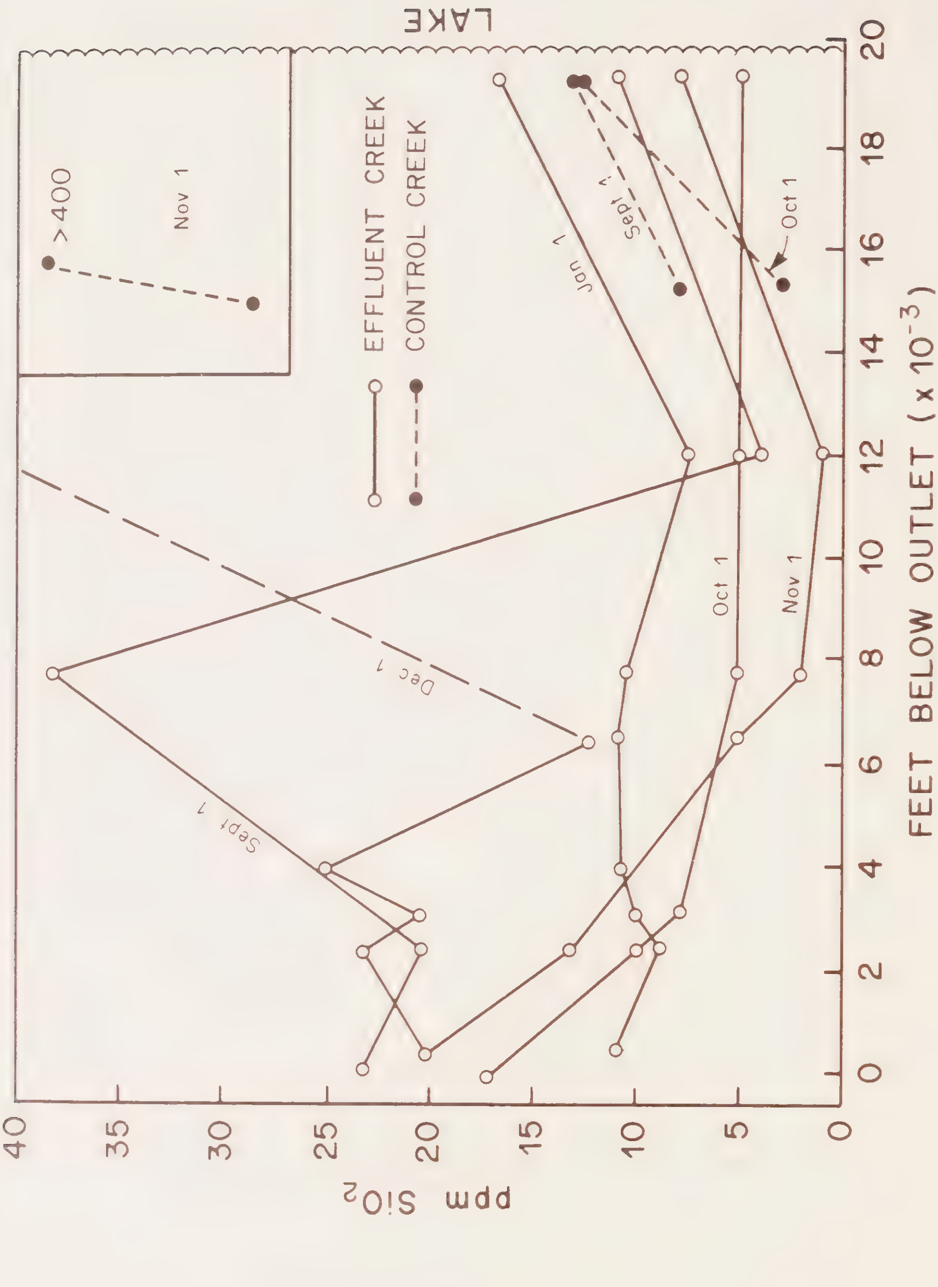

LAKE
TEMPERATURE (°C)
FEET BELOW OUTLET (x 10⁻³)
EFFLUENT CREEK
CONTROL CREEK
Aug. 25
Sept. 1
Sept. 8
Sept. 15
Sept. 22
Sept. 29
Oct. 6
Oct. 20
Oct 23
Nov. 10
0
2
4
6
8
10
12
14
16
18
20

Figure 2 TURBIDITY



value for Site E-5 on 1 December is doubtless due to an isolated event.

6.3 Chemical Parameters in the Effluent and Control Creeks

6.3.1 Biochemical Oxygen Demand

Fig. III shows that BOD_5 falls rapidly with distance below the outflow, the greater proportion of this reduction occurring in the first 1,000 m. The rate of decrease appears to be somewhat slower as the water temperature falls but is still very substantial as late as 20 October. There is no significant difference between the BOD of the two creeks below the top 1,000 m of the effluent creek, except for the single high figure for the site E-5 on 26 January.

6.3.2 Chemical Oxygen Demand

As Fig. IV shows, there is a general downward trend to COD as the outflow is approached; the values are however high in both the control and effluent creeks. This, coupled with the close correlation between the figures for COD and Total Organic Carbon (q.v.), suggests that the COD is generated by both sewage materials and by naturally occurring organic materials. As for BOD, site E-5 showed a high peak on 26 January; Total Organic Carbon also peaked at that time at E-5.

6.3.3 Dissolved Oxygen

Fig. V shows that prior to November the oxygen concentration rose rapidly as the effluent creek flowed downstream from the sewage outflow. However by November 1 this rise

Figure 3 BIOCHEMICAL OXYGEN DEMAND (BOD)

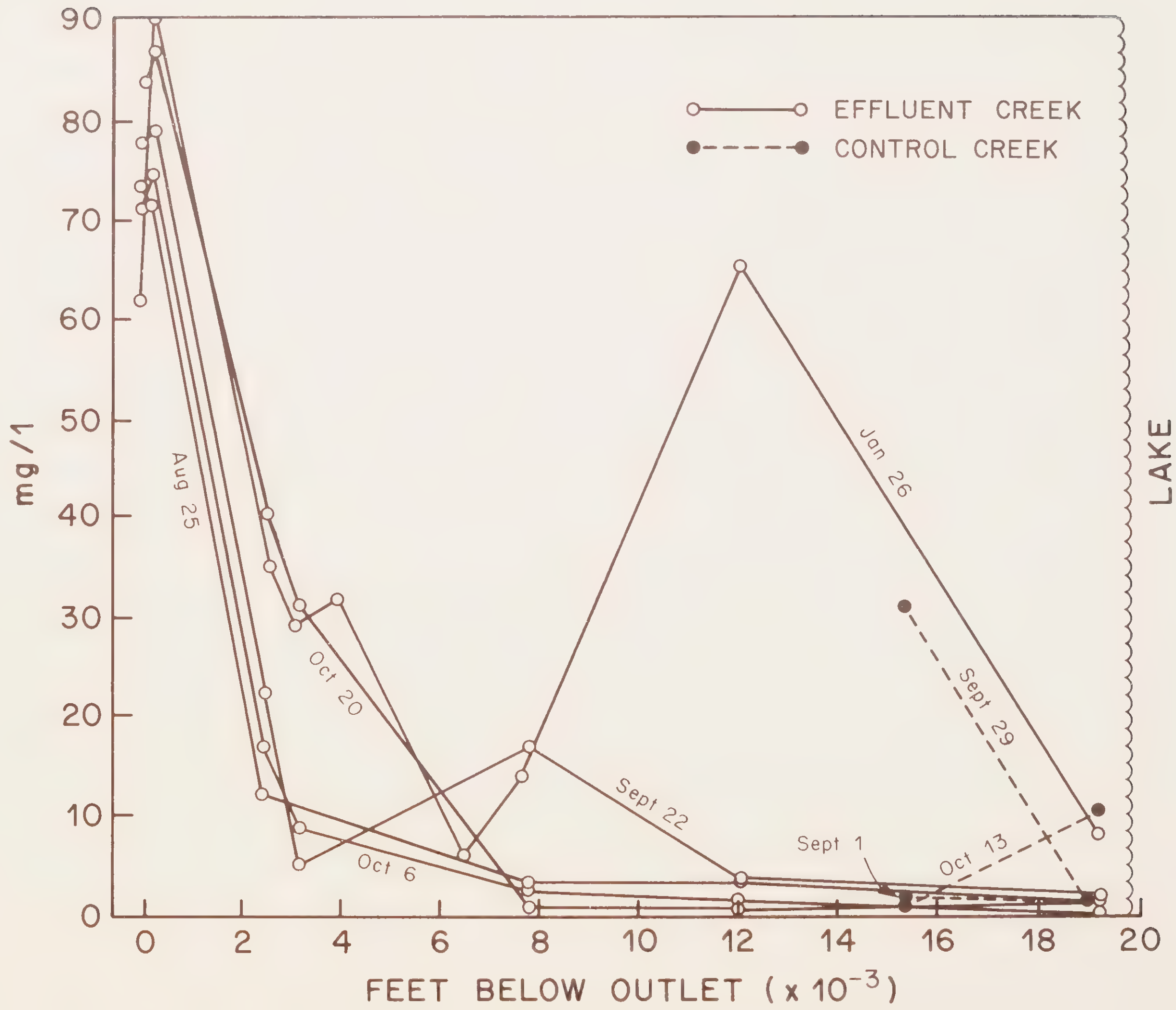


Figure 4 CHEMICAL OXYGEN DEMAND (COD)

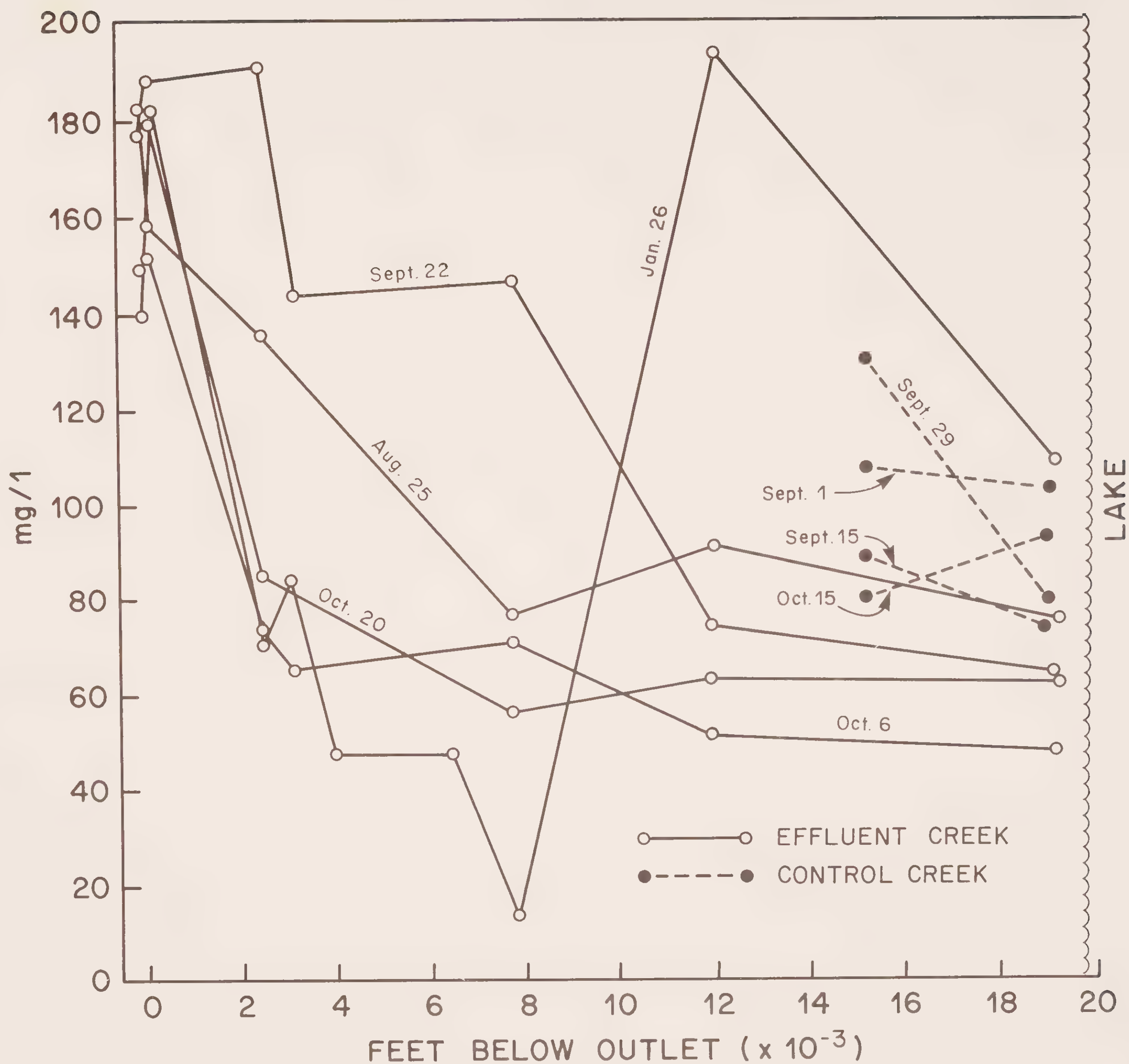
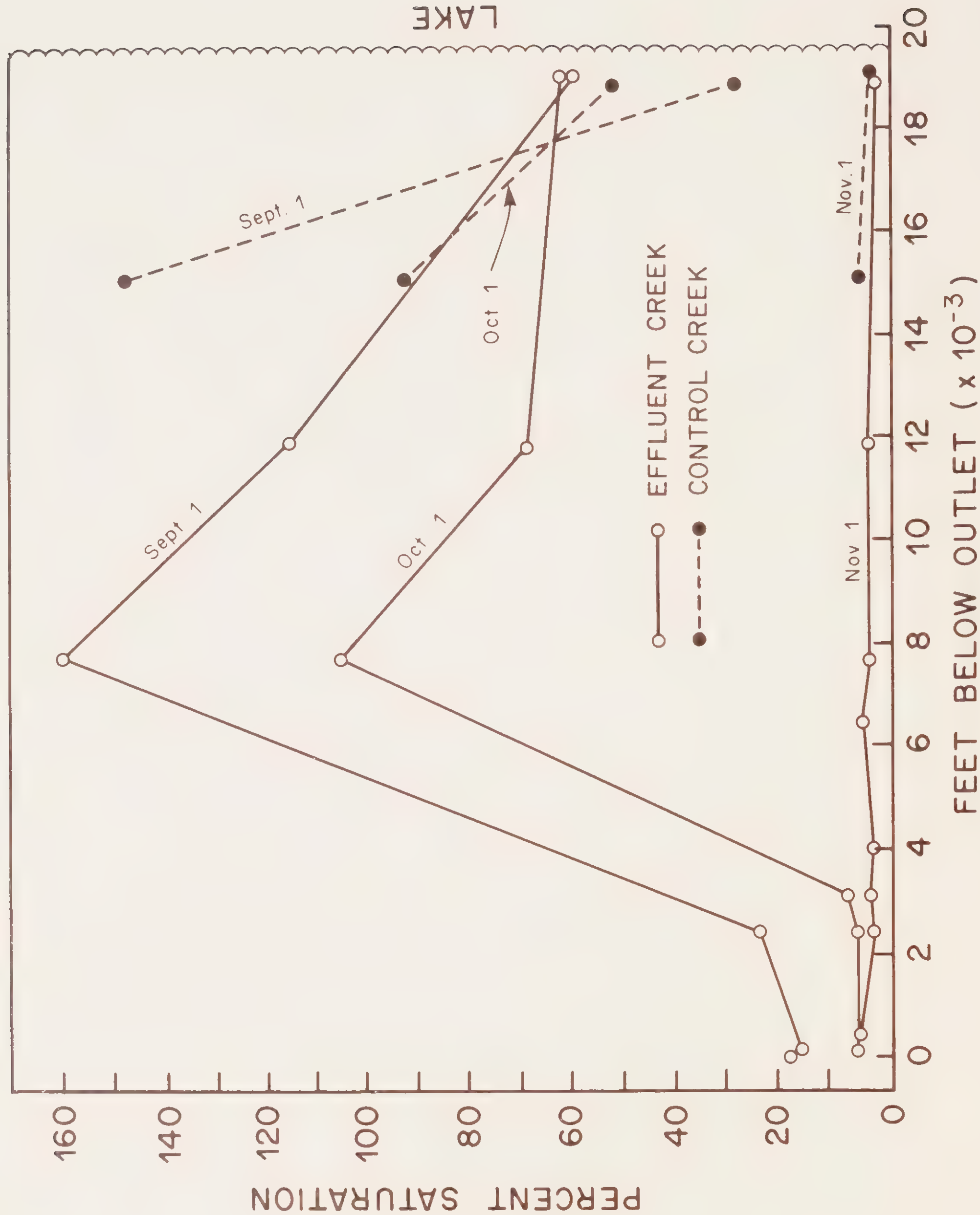


Figure 5 DISSOLVED OXYGEN



did not occur, presumably due to the presence of ice cover. Oxygen concentrations were above saturation values at sites 4 and 5, due to the intense photosynthesis at these locations. The downstream fall in oxygen concentration in both creeks is doubtless due to the high concentrations of organic debris accumulating in the slow-moving lower reaches. Oxygen concentrations remained low in December and January, never reaching more than 10% saturation in either the Effluent or Control creeks.

6.3.4 Ammonia

Fig. VI shows that the drop in ammonia occurs within the upper 3,000 metres of the effluent creek. There is an inverse relation between the concentrations of ammonia and dissolved oxygen, the ammonia curve falling slowest when the oxygen level has fallen (1 November) to a low value. This pattern was also followed in December and January.

6.3.5 Hardness

Fig. VII reveals that there is an upward trend in hardness in the effluent creek from the outflow to the mouth, the values at the mouth being close to those for the control creek. It may be noted that all the values for Total Hardness are higher than those in Grainge (1971) which seem improbably low, and which are much lower than those in Grainge (1970).

Figure 6 AMMONIA NITROGEN

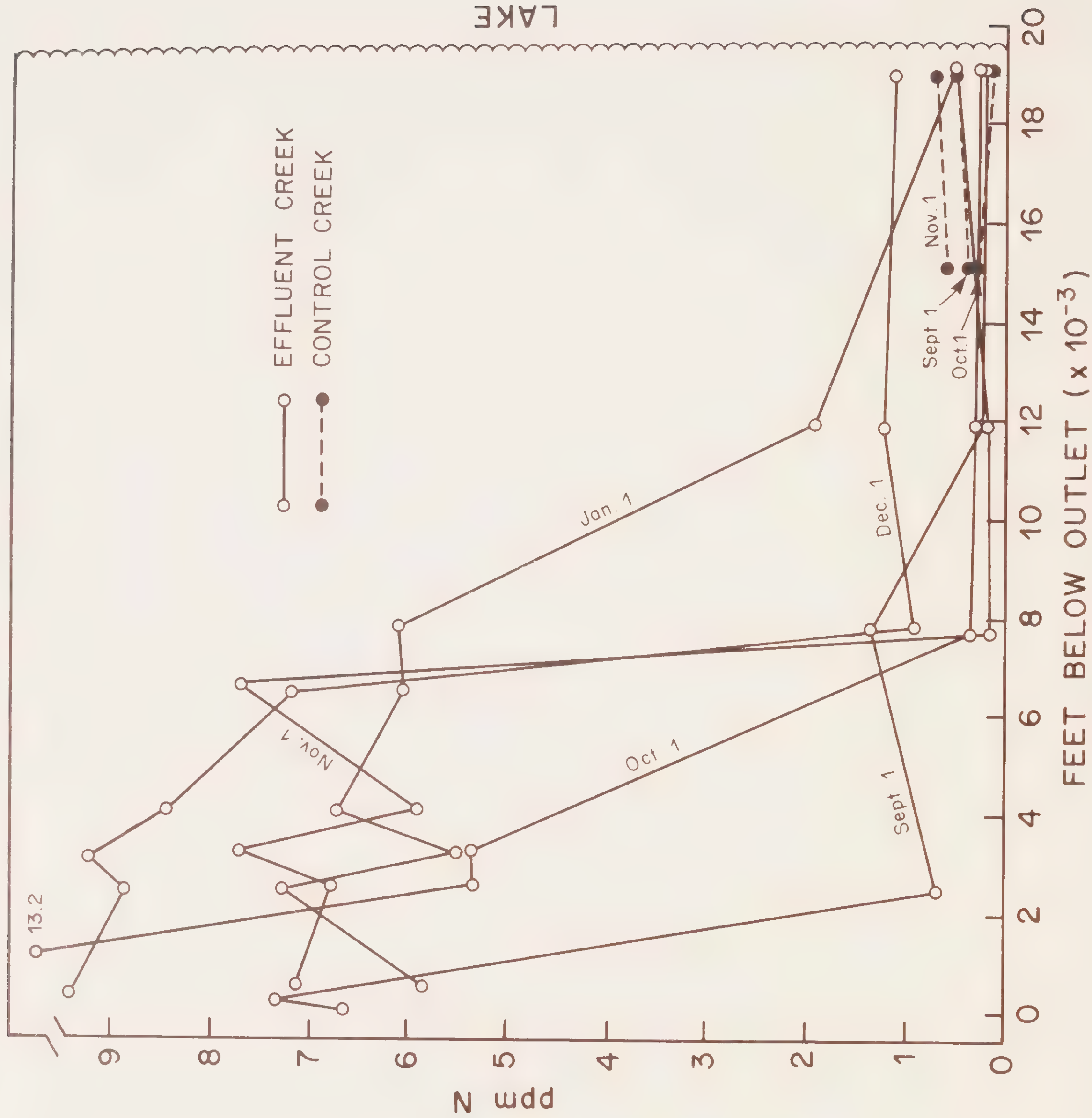
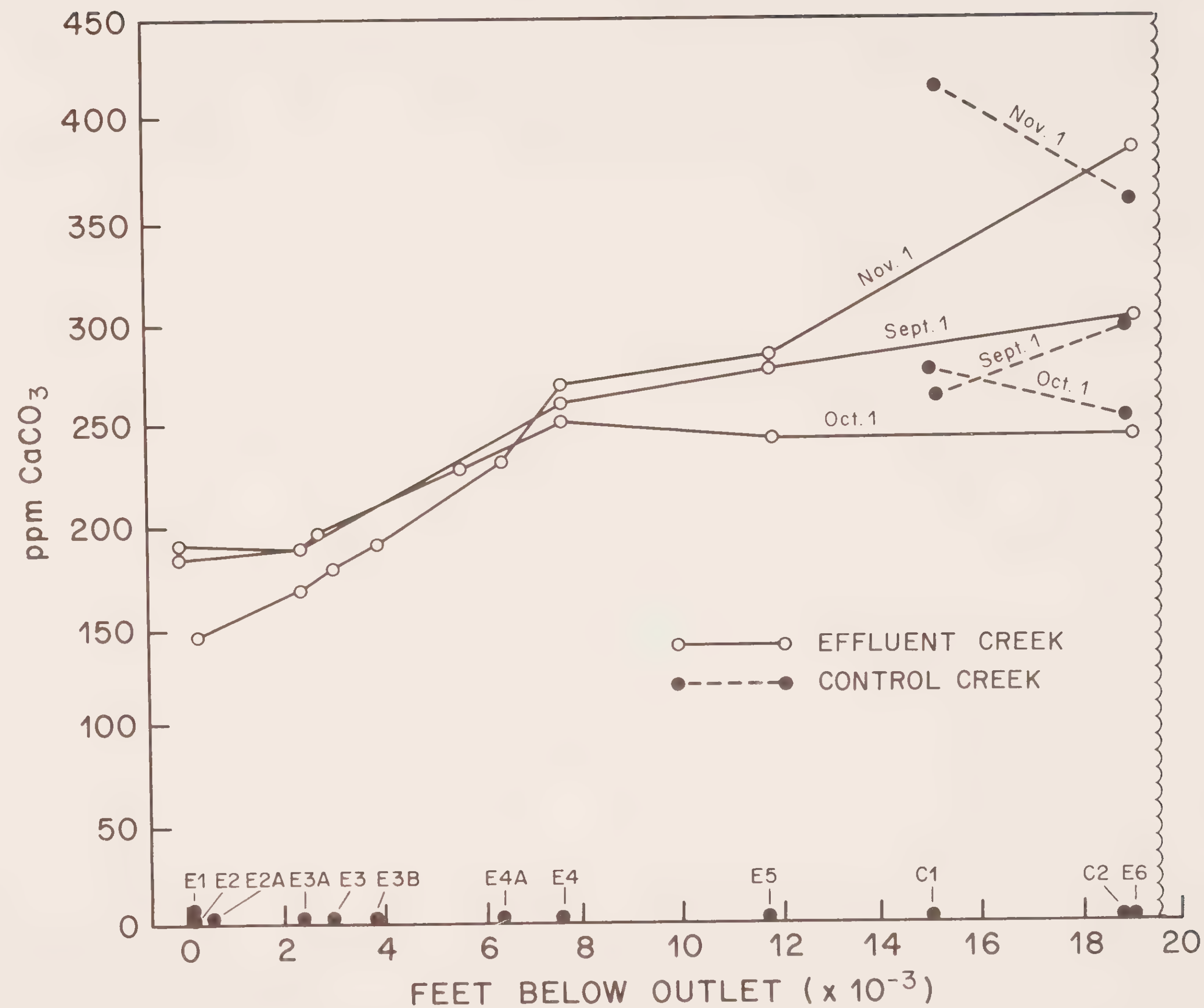


Figure 7 TOTAL HARDNESS as $CaCO_3$



6.3.6 Nitrates and Nitrites

Fig. VIII reveals that the concentration of nitrate + nitrite was usually less than 0.1 mg/l, and usually close to 0 mg/l. The high figure of 5.0 on 1 October may be due to error, and the excessive figure of 5.0 mg/l on 1 September is attributable to poor storage of the sample for that date.

6.3.7 Sulphates and Sulphites

Fig. IX shows the concentrations of sulphates in the control and effluent creeks. It is evident that there is a rapid drop in sulphate in the effluent creek. It appears that a substantial proportion of this fall in concentration is due to reduction from sulphate to sulphite, since Fig. X shows a corresponding rise in sulphite. Moreover the sulphite level is high in both effluent and control creeks. It is noteworthy that the rise in sulphite concentration is shifted downstream in January as compared to previous months.

6.3.8 Phosphate

Fig. XI reveals that there is a rise in phosphate level between the outflow and sample station 3, followed by a drop to a level similar to that of the control creek by station 5. The increase upstream is due to bacterial degradation of organic material in the sewage material and the drop downstream from station 5 is due to the removal of phosphate by the aquatic vegetation. From November onwards the upstream concentration of phosphate

Figure 8 NITRATE + NITRITE NITROGEN

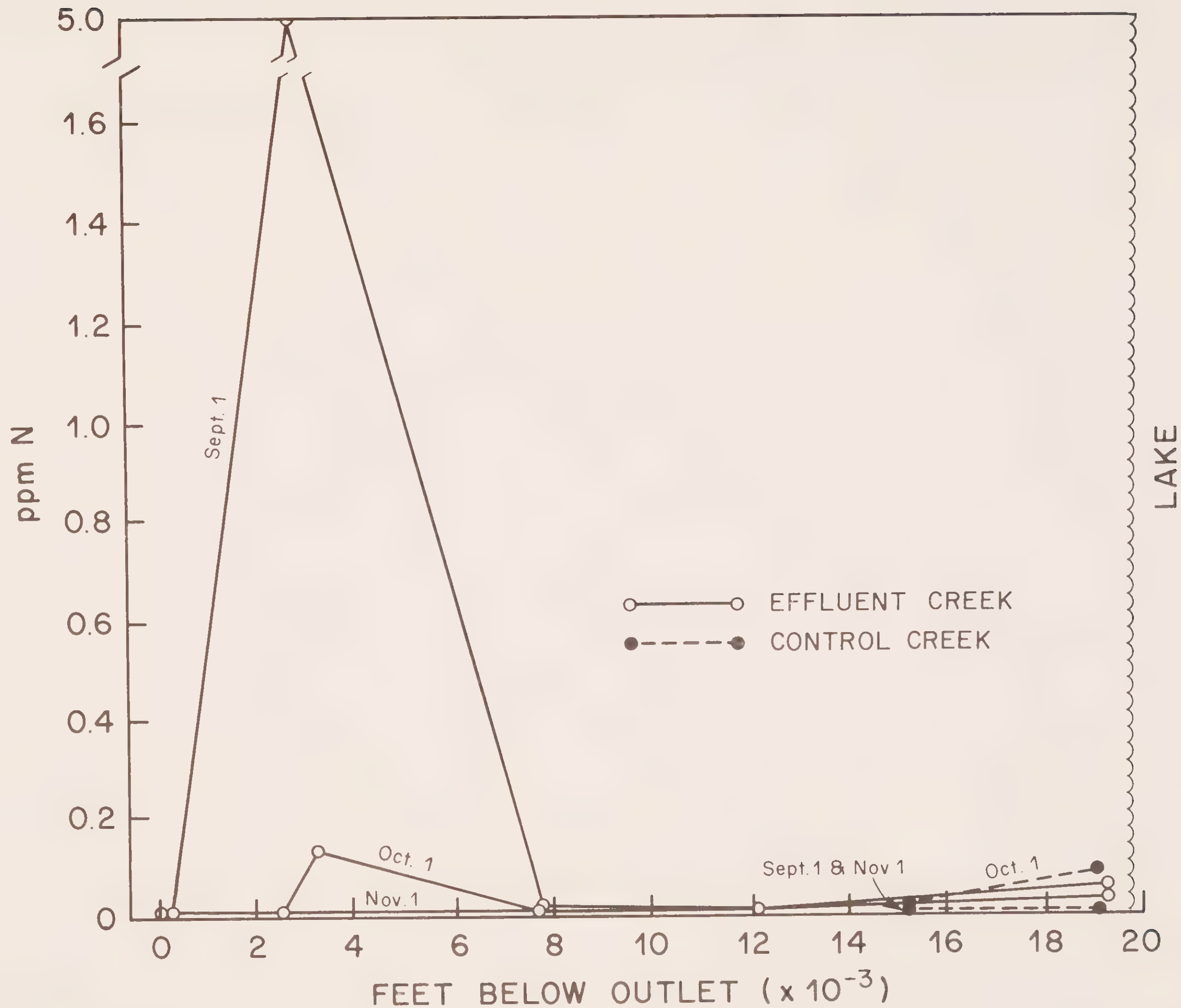


Figure 9 SULPHATE

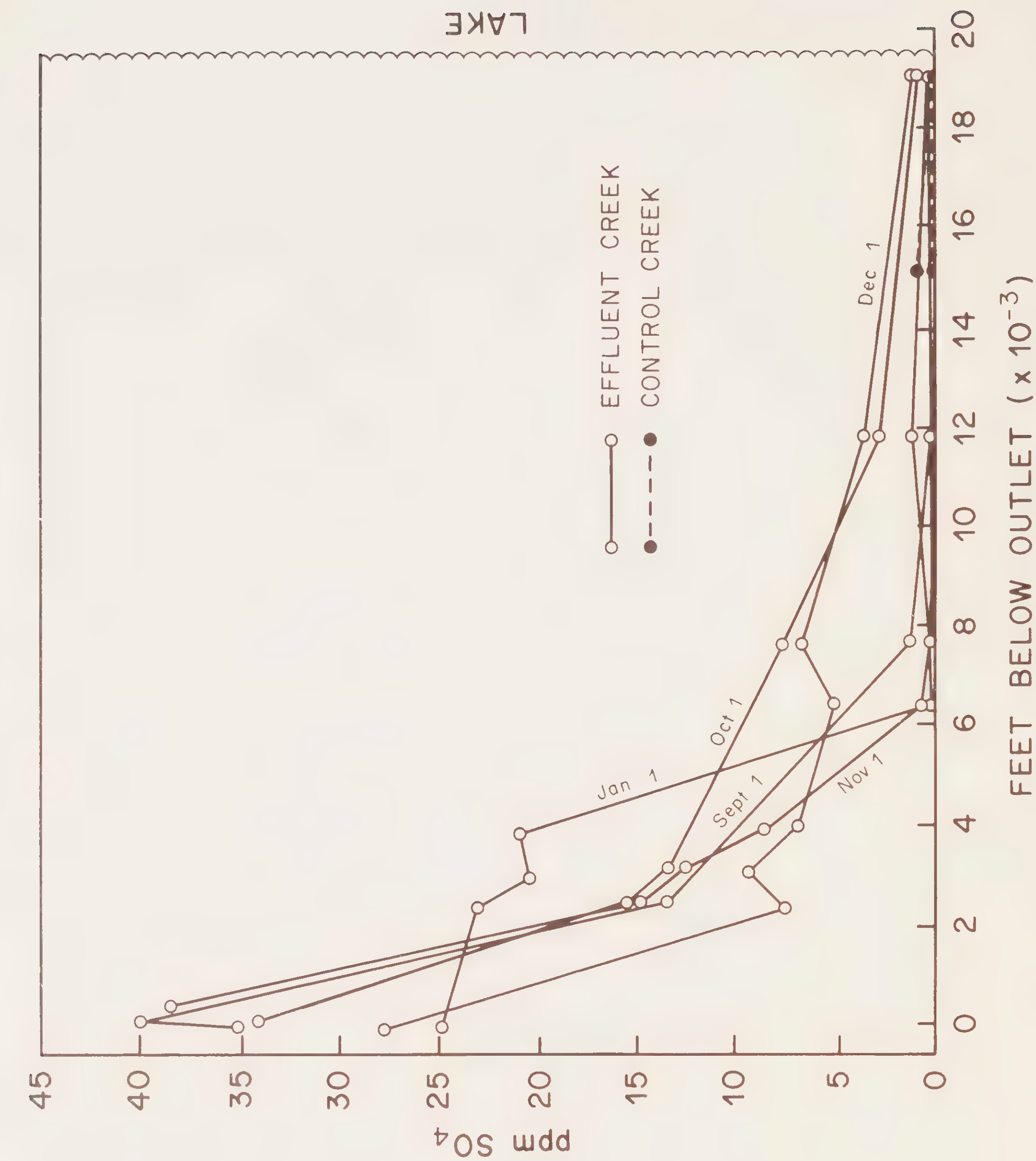


Figure 10 SULPHITE

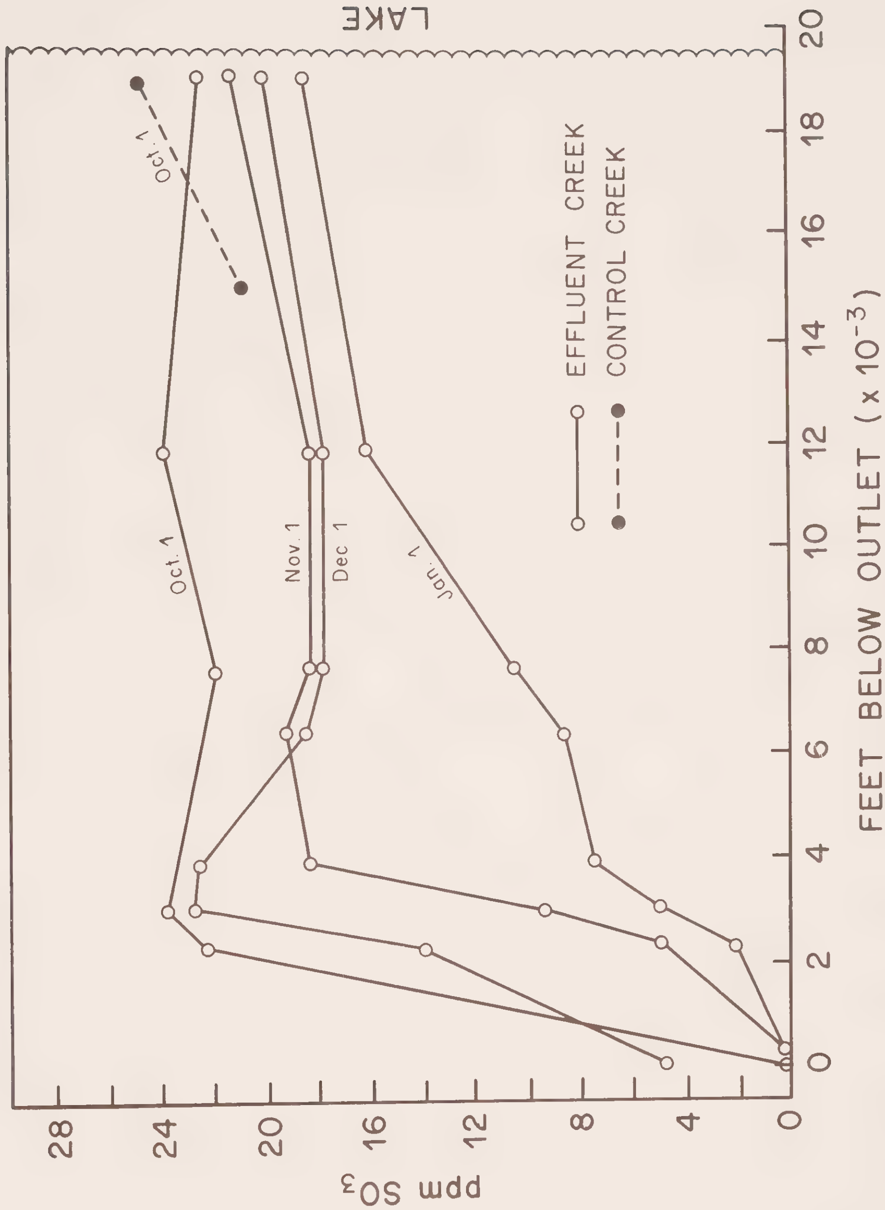
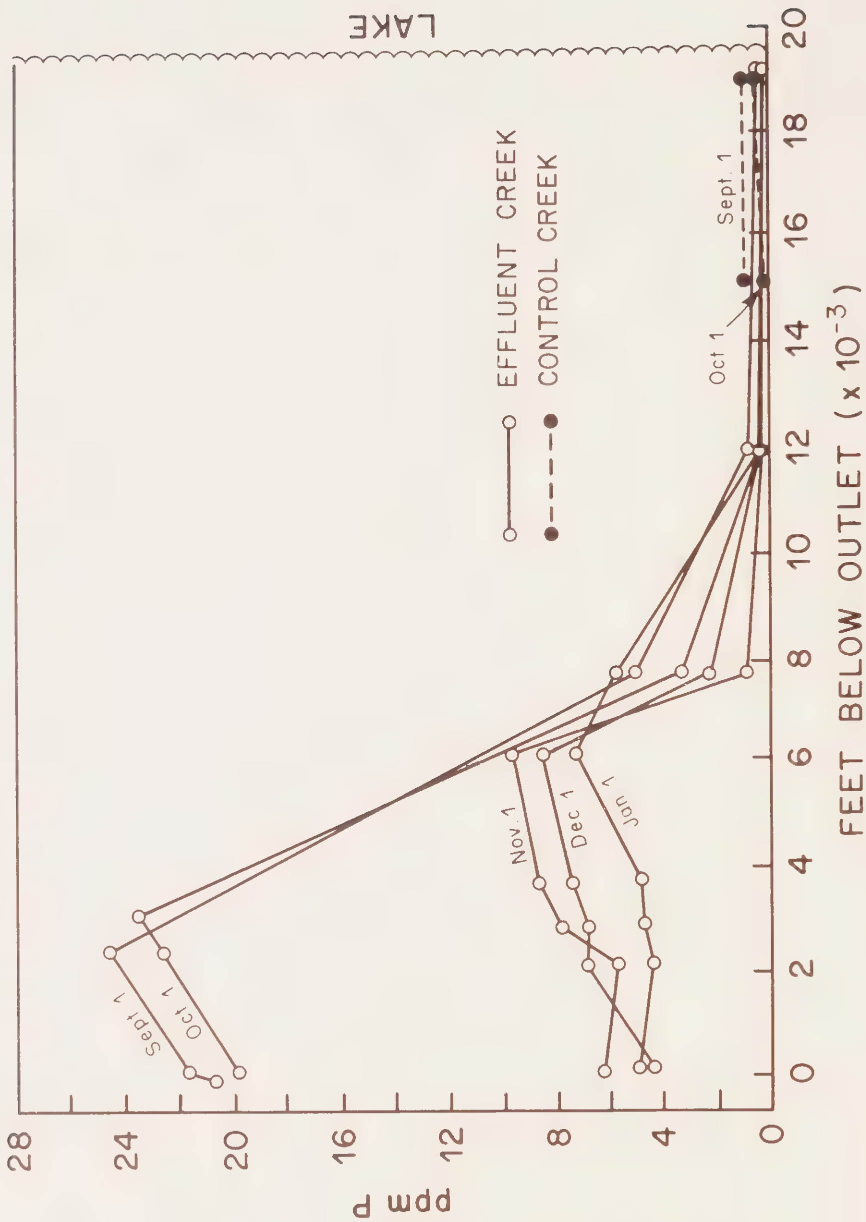


Figure 11 TOTAL PHOSPHATE PHOSPHORUS



is reduced, and the maximum is observed at site 4 rather than at site 3.

6.3.9 Organic Carbon

The levels of dissolved organic carbon in the two creeks are comparable as shown by Fig. XII. Moreover there is a close similarity between the values for TOC and for COD (vide supra).

6.3.10 Average Effluent Quality August to November 1972

From the data obtained from August to November 1972 the average values for certain parameters have been calculated both for the lagoon effluent and the sewage truck material. Table III gives the details of these figures and a comparison of the results with the average figures for these parameters at site E5 which is approximately 4,000 metres from the outflow.

6.4 Bacteriological Results

6.4.1 Total Coliform Counts (MPN Method)

As Fig. XIII shows, values for total coliform counts are generally very low in the effluent creek from site E4 downstream, and apart from one exceptional value (site C2 on 1 September), are low in the control creek.

The data at the upper sample sites on the effluent creek show high variability. By January the zone of high concentration has shifted downstream to site 4, but by site 5 the values have, as before, fallen to very low values.

Figure 12 TOTAL ORGANIC CARBON

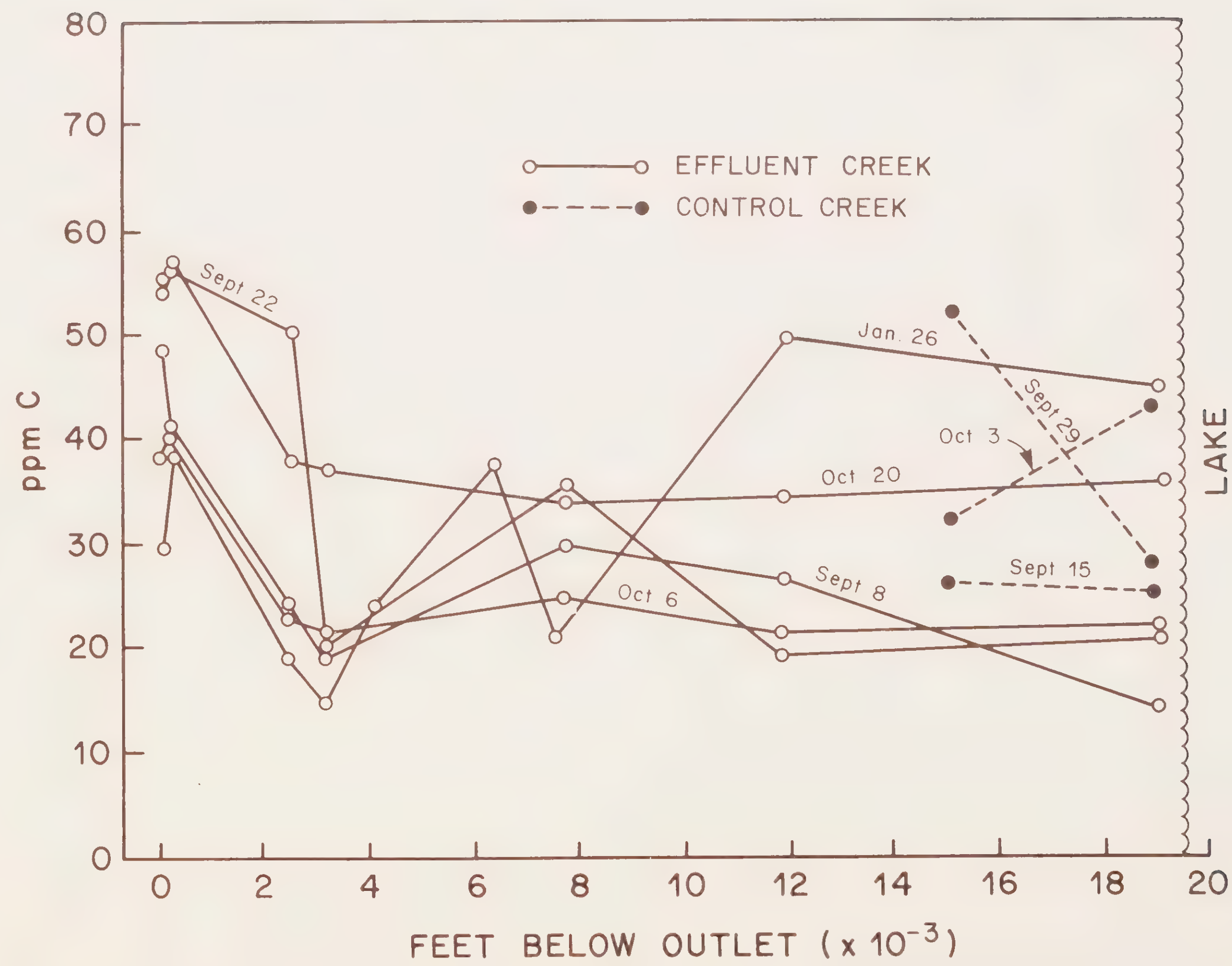


Figure 13 TOTAL COLIFORM BACTERIA

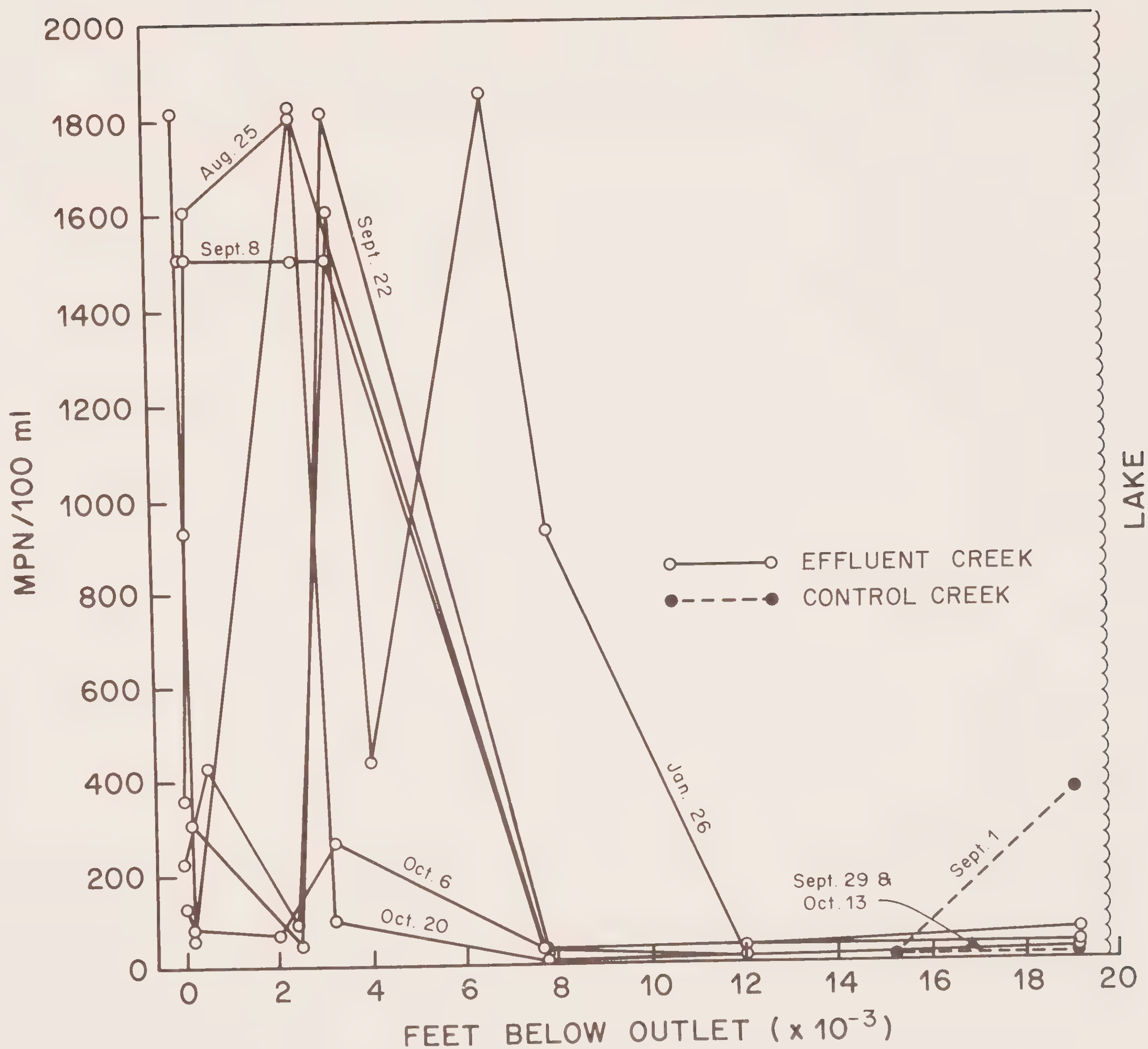
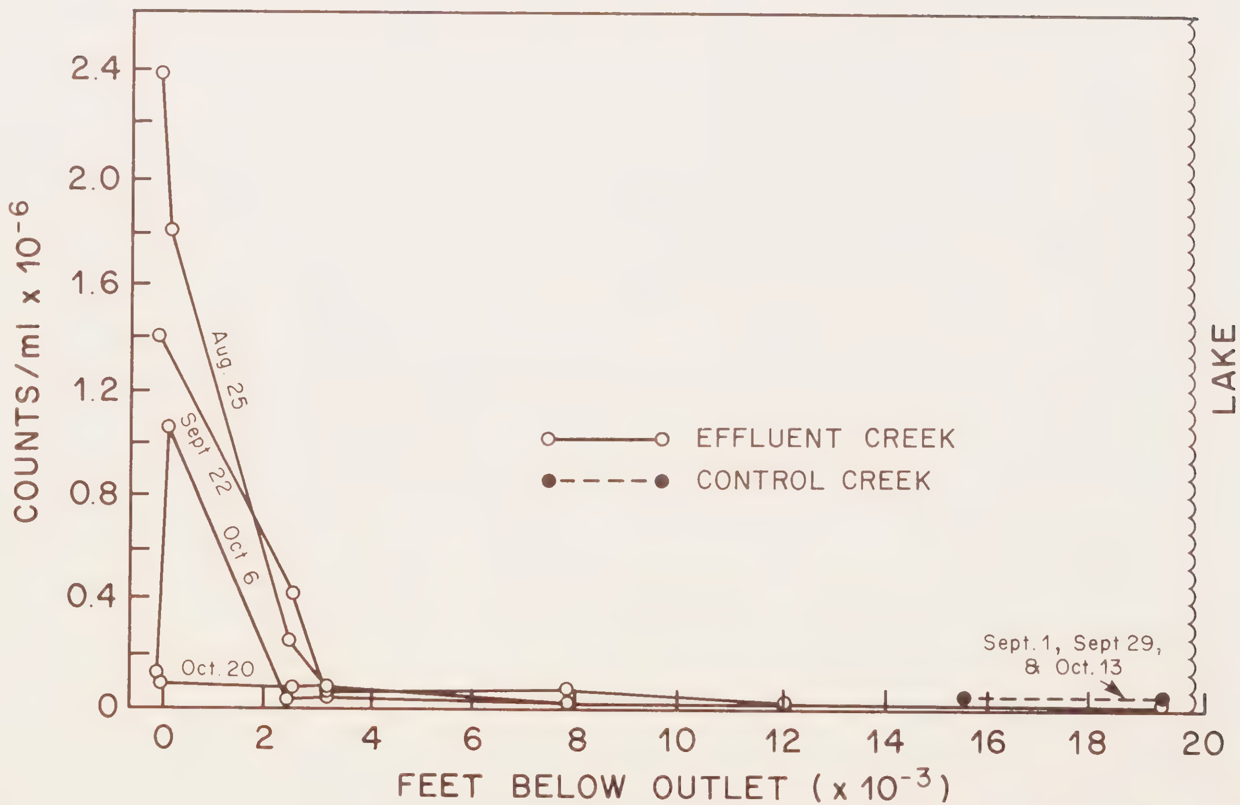


Figure 14 STANDARD PLATE BACTERIAL COUNT



6.4.2 Standard Plate Counts

As Fig. XIV shows, the standard plate counts fall rapidly at the upper end of the effluent creek and are low in the control creek. Like total coliform counts, the standard plate counts fall most rapidly at lower temperatures.

6.4.3 Fecal Coliform Counts

Fecal coliform counts ranged from 0-24/100 ml. Somewhat higher values were found at sites E1, E2, E3A and E3 than downstream on the effluent creek, the mean for these four sites over the period 25 August to 20 October being 8.4/100 ml. compared to a mean of 1.8 for the remaining three sites. Results for the control creek were negative except on one occasion when 4.5/100 ml. were recorded at sites C2. There appears to be a rise in the mean count from 25 August to 20 October in the effluent creek. The data for November, December and January reveal considerable fluctuations, suggesting that at least some of the counts are derived from bacteria from animals, such as muskrats which are present in the Effluent creek.

6.5 Vegetation

6.5.1 General Observation at the Sample Sites

At site E3A the floating mat vegetation is very dense and consists of an almost pure stand of *Typha latifolia* L. and *Carex* species. *Lemna minor* L. is moderately abundant at the margins, but submergent vegetation is absent.

TABLE III

AVERAGE EFFLUENT QUALITY COMPARED TO AVERAGE WATER QUALITY AT SITE E5

ALL VALUES ARE IN MG/LITRE - AUGUST TO NOVEMBER 1972

	Lagoon Effluent	Sewage Truck	Proportions Based On Flows: Lagoon Outlet	+	Sewage Truck	=	Average	Conditions at E_5	% Reduction
BOD	75.5	494	69.5	+	71.6	=	141.1	2.6	98.2
COD	169.0	1141	144.5	+	166.0	=	310.5	71.9	76.9
Alkalinity as $CaCO_3$	223.0	356	190.5	+	51.6	=	242.1	256.6	-5.9
Ammonia Nitrogen	9.0	48	7.7	+	7.0	=	14.7	.31	97.9
Nitrate	.007	.13	.006	+	.019	=	.025	.009	64
Nitrite	.004	.010	.0034	+	.001	=	.0044	.0033	25
Phosphate Total Soluble	20.5	42.3	17.15	+	6.15	=	23.3	.28	98.8
Total Carbon	106.0	390.0	90.7	+	56.6	=	147.3	89.0	39.6
Inorganic Carbon	50.0	82.0	42.8	+	11.9	=	54.7	60.5	-10.6
Organic Carbon	56.0	308.0	47.8	+	44.7	=	92.5	27.0	70.9
FLOW GAL./DAY	177,000	30,000	207,000 gal./day						

At site E4 there is a greater number of species represented in the floating mat which here consists predominantly of Carex but also includes such grasses as Glyceria and Phalaris as well as shrubs such as Alnus. Submerged vegetation consists predominantly of the moss Drepanocladius fluitans in shallower areas and Utricularia in the deeper areas, as well as Nuphar variegatum, Lemna minor, Sparganium and Potamogeton. The standing crop of vegetation appears to be less at E4 than at either E3A or E3. Site E5 has a slightly lower standing crop than at E4. In addition to the species found at E4 there are at E4 Typha, Ranunculus and Hippuris. The most abundant forms are Drepanocladium fluitans, Utricularia and Carex.

At E6 the species composition is similar to that at E5 but the standing crop is substantially lower and no species are predominant. Submerged vegetation does not occur at this site in water deeper than 1 metre.

At sites C1 and C2 the species composition and standing crop are similar to those at E6.

There is a striking difference between sites E3A and E3 and all other sites on either creek, the others all displaying the presence of submergent vegetation, and substantially wider diversity.

6.5.2 Emergent Vegetation

Samples of annual emergent vegetation have been collected for estimation of production, but the final results are not yet available.

Samples of vegetation have been cut for estimation of standing crop dry weights. The samples have not been fully dried and the data below refer to material which is probably roughly of equivalent moisture content.

Location	Vegetation type	Semi-dry weight $/m^2$	
E3A	Carex	775 gms)	2560 gms
E3A	Typha	1785 gms)	
E3	Carex		1116 gms
E5	Carex	315 gms)	621 gms
E5	Typha	306 gms)	
E6	Mixed		282 gms

These preliminary data clearly support the visual observation that the maximum growth of emergent vegetation occurs in the upstream portion of the effluent creek.

6.5.3 Submerged Vegetation and Phytoplankton

Phytoplankton data have not yet been processed but preliminary examination of data on the submerged vegetation shows clearly that diversity in September was depressed at the upstream sites, but had recovered by Site 4. The figures below show Diversity Indices (Shannon's Index) for five sites on the effluent creek and two on the control creek.

Site Number	Shannon Index
E3A	1.089
E3	1.061
E4	2.170
E5	2.432
E6	2.398
C1	2.210
C2	2.197

6.6 Zooplankton

Although analysis of zooplankton samples is not completed it is obvious that sites E3A and E3 show a narrower range of organisms than the other sites on the effluent creek. Moreover no zooplankters were obtained at either of these sites (nor at E6 and C1) on 1 November. It may be significant that these sites are the ones at which dissolved oxygen levels are lowest. When winter samples are taken it will be possible to determine whether all zooplankton disappears during the winter. None was seen during the preliminary survey in May 1972. The greatest number of species was found in both October and November at sites E4 and E5. During December and January there was found to be virtually no zooplankton present in either creek, only a single Cyclopoid and few rotifers being observed.

6.7 Nekton and Benthos

Sites E3A and E3 reveal an improvished nektonic and benthic fauna compared to the other sites on both creeks. Larvae of Chironomidae were the only forms obtained at E4 and E5, support a wide range of nektonic and benthic animals, including Crustacea (Gammarus), Insecta (Ephemeroptera,

Odonata, Hemiptera, Coleoptera, Trichoptera, Diptera), Mollusca, and various other forms. These comments are supported by the figures below showing Shannon Index values for October and November.

Site Number	Shannon Index (October)	(November)
E3A	0	-
E3	0.868	-
E3B		0.683
E4A		1.280
E4	2.379	1.581
E5	2.406	2.138
E6	1.321	0
C1	2.216	1.280
C2	1.242	0.683

(- signifies no organism present; 0 signifies no diversity (i.e. a single species present); a blank signifies that no sample was collected at that site)

It is not possible to collect comparable samples during the period of thick ice cover owing to the danger of excessive habitat disturbance; a small number of specimens have been collected through the holes made in the ice for water sampling purposes, but these are not a representative sampling.

6.8 Fish

Members of the pike family (Esocidae) have been observed at sites E4, E5 and E6, but none have been captured for specific identification.

7. Discussion

7.1 BOD and Phosphate Removal in the Effluent Creek Watershed

Table III shows the mean changes in certain parameters in the effluent creek between the lagoon outflow and sample site E5 for the period August to October 1972. If the mean flow is taken to be the figure mentioned in section 6.1.2 (207,000 Imp. gals. per day), it can be calculated that the mean removal between the outflow and E5 is 287 lb/day for BOD and 47.8 lb/day for phosphates. Taking the area of watershed between these points as 31.82 ha., the annual load per square metre is found to be 150 gm. BOD and 25 gm. phosphates.

It is evident from the data presented in Table III that the swampland upstream of site E5 acts as an efficient secondary, and to some extent, tertiary sewage treatment, at least for the period under consideration. BOD was reduced by 98.2% and total soluble phosphate by 98.9%.

It is of interest to compare these data with those obtained by Grainge and Shaw (1970) and partially summarised in Table I. Although their data compare raw sewage with the water of the effluent creek at its outflow into Great Slave Lake, while the present data span a smaller extent of the creek, the reductions of both BOD and phosphates are very similar.

7.2 Bacterial Removal in the Effluent Creek Watershed

Because of the erratic results obtained upstream it is not possible to obtain a meaningful average figure for the most

probable number of total coliform bacteria at the outflow. However the upstream figures are frequently in the neighbourhood of 1600/100 ml. whereas at site E5 the average is less than 12/100 ml. suggesting that the reduction is in the neighbourhood of 98%. The counts for fecal coliform bacteria are too small and too variable to permit any judgment.

7.3 Sulphites in the Effluent and Control Creeks

An unusual feature of the results is the high sulphite levels observed both in the control and effluent creeks. Sulphites do not normally occur in significant concentrations in unpolluted waters, usually being either reduced to sulphides or oxidised to sulphates. In the effluent creek there appears, from the inverse relation between sulphite and sulphate, to be an incomplete reduction of sulphate occurring; the fact that sulphite levels are very similar in the control creek suggests that this also occurs in that creek.

It is of interest that it has been found (Krouse, et al. 1970), in studies on isotope fractionation by microorganisms, that sulphate-reducing species of bacteria sometimes occur in pairs, one reducing sulphate to an intermediate valence state and the other completing the reduction to sulphide. It is hoped that further study may reveal whether the high sulphite concentrations might be due to microbial activity.

8. Conclusions

8.1 The condition of the stream into which the Hay River sewage effluent flows is, after a distance of some 6,000 metres, almost indistinguishable from that of a control creek in the vicinity.

8.2 Most of the undesirable chemical and biological conditions observed at the sewage outflow have been ameliorated with the first 2,500 metres of the stream (i.e. above site E4). At sites E4 and E5 the condition of the stream and its watershed, judged on biological and chemical criteria, betray no evidence of harmful effects of effluent addition. The condition of the creek, judged by the same criteria, is poorer at site E6 close to Great Slave Lake, but the same is true of the control creek.

8.3 The quality of the water, judged on chemical criteria, is as high at the mouth of the effluent creek as at the mouth of the control creek. It is not significantly different in 1972 from its condition in 1970 when the sewage effluent had been flowing into the creek for only two years.

8.4 Deleterious effects on the watershed, in terms of altered biological communities, can be detected in the upper portions of the effluent creek, the area involved being approximately 78,000 square meters.

8.5 Of the BOD and phosphate loading to the effluent creek watershed, a disproportionate amount is derived from the dump trucks whose loads are placed directly into the creek.

8.6 Since the sewage lagoons were brought into operation in 1968 it is estimated that the average contributing population has been about 1,600 people. The current contributing population is about 2,000 people. The effluent creek has thus received, since effluent began to be released into it, sewage effluent for about 6,400 man-years.

8.7 It is not at present possible to determine whether the swampland is yet in stable equilibrium with the incoming effluent load. If it is assumed to be in equilibrium, it can be calculated that the area of affected swampland per man-year of effluent is less than 15 square metres. If it is assumed that the present condition involves no progress toward equilibrium (i.e. that it represents the cumulative effect of sewage inflow throughout the four-year period), then it must be concluded that the creation of damaged swampland occurs at a rate of roughly 40 square metres per man-year of sewage effluent.

9. Implications and Recommendations Concerning Sewage Release into Swampland

9.1 General Comments

The results of this study so far confirm the observations of Grainge and Shaw (1970) and Grainge and Frith (1971) that northern swampland acts as an efficient site of secondary and tertiary sewage treatment at the loads observed at Hay River. Although it has not yet been determined whether the receiving swampland at Hay River is in a condition of stable equilibrium in relation to the present annual loading, it is evident that the area affected is not excessive.

9.2 Specific Comments Related to Pipeline Development and the Hay River Area

As is pointed out in section 8.7, it is not yet possible to conclude that the swampland in the effluent creek watershed at Hay River is in equilibrium. At worst - that is, assuming that it is not - the data from Hay River suggest that approximately 40 square metres of swampland are adversely affected, over a four-year period by receipt of primary-treated sewage effluent from one man for one year. This study has not shown, nor will it show, the time necessary for the recovery of such damaged swampland.

9.3 General Recommendations

The following general recommendations are made on the premises that: (1) damage to swampland of the nature observed at Hay River is acceptable, and (2) that any sewage effluent discharged into swampland is at least equal in quality to

that released from the primary lagoons at Hay River.

9.3.1 It is recommended that, in addition to existing regulations governing the operation of sewage facilities in the Northwest Territories, primary treated effluent be released into natural swampland only:

(a) in locations where such swampland includes an existing creek watershed supporting a substantial growth of *Carex* species,

(b) where such creek watershed is flat and broad enough to include substantial pools with low flow rates of water,

(c) where such watersheds flow for at least six miles before either approaching human habitations or flowing into rivers or lakes.

9.3.2 It is recommended that the release of primary treated effluent into swampland not be permitted for more than four years in the first instance, and that an allowance of no less than 100 square metres of creek watershed be made for each contributing man-year.

9.4 Specific Recommendation Concerning Hay River Effluent

In view of the disproportionate contribution to the sewage load of the effluent creek received from the dump trucks (see Table III), it is recommended that the practice of dumping sewage directly into the creek be halted immediately, and that all such sewage be passed through the lagoons.

(It may be noted that a similar recommendation was made in Grainge and Shaw (1970 MS) and Grainge and Frith (1971 MS); some minor road modification will be necessary to provide truck access to the lagoons).

10. Needs for Further Study

10.1 Existing Gaps in Knowledge

This study is providing information bearing on the utilisation of swampland at Hay River, but there are four principal questions which remain unanswered by the study. These are:

(1) Can the observations at Hay River be duplicated in a harsher northern climate?

(2) Has the system now reached equilibrium?

(3) How rapidly can affected swampland recover?

(4) Is the efficiency of the system limited by the rate of nutrient uptake by macrophytes or by the rate of nutrient release by microorganisms?

10.2 Proposal for Additional Studies

In the light of the foregoing comments, the following proposals are made for further study.

10.2.1 Effect of Climate on Sewage Nutrient Uptake by Swampland

The present study has shown that the removal of nutrients by swampland at Hay River is highly effective, more than 98% of phosphates being removed. It is proposed that a small-scale study be conducted at one or more sites in harsher northern climates to determine whether the same order of efficiency exists. The cost of such a study would be small, since it need involve only the collection and analysis of water samples from selected sites.

10.2.2 Equilibration of the Effluent Creek at Hay River

Short-term study cannot demonstrate whether the

condition of the creek is now an equilibrium between effluent receipt and nutrient removal or whether the affected portion of the creek is expanding. It will be highly desirable to establish a biennial mapping programme for a period of ten or more years to detect any expansion of the affected area.

10.2.3 Recovery of Effluent-affected Swampland

Since the Hay River effluent creek continues to receive sewage effluent it is impossible to determine how rapid recovery might be. Since pipeline and other development in the North may involve temporary work camps it will be advisable to assess the probable duration of the effect on swampland which has received sewage effluent for a limited period of time. Treatment of a selected site, perhaps near Hay River, for at least one full summer, followed by careful observation through the next two summers and thereafter biennially should enable an answer to this question to be provided.

10.2.4 Nutrient Removal by Swampland

Although the present study has shown that swampland can be highly effective in removing nutrients from sewage effluent it cannot show whether the efficiency of removal is limited by the rate of nutrient release from the sewage or by the rate of nutrient uptake by the macrophytes. Combined field and laboratory studies will enable an answer to be provided to this question; this may be of practical significance in assessing the potential of

particular areas of natural swampland for utilisation as sinks for sewage effluent.

11. References

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APPENDIX I

LIST OF EQUIPMENT

1. Chemical Analysis System; Series 260, Delta Scientific Corp., Lindenhurst, N.Y.
2. Chemistry Kit; Model AL-36-P, Hach Chemical Co., Ames, Iowa.
3. Conductivity Meter; Model RA-2A, Beckman Instruments Inc., Cedar Grove, N.J.
4. Oxygen Meter; Model 54, Yellow Springs, Ohio.
5. pH Meter, Model PBL, E.H. Sargent and Co., Chicago, Illinois.